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## 8. DERMAL ROUTE

### 8.1 INTRODUCTION

Children may be more highly exposed to environmental toxicants through dermal routes than adults. For instance, children often play and crawl on contaminated surfaces and are more likely to wear less clothing than adults. These factors result in higher dermal contact with contaminated media. In addition, children have a higher surface area relative to body weight. In fact, the surface-area-to-body weight ratio for newborn infants is more than two times greater than that for adults (Cohen-Hubal et al., 1999).

Dermal exposure can occur during a variety of activities in different environmental media and microenvironments (U.S. EPA, 1992a; 1992b). These include:

- Water (e.g., bathing, washing, swimming);
- Soil (e.g., outdoor recreation, gardening, construction);
- Sediment (e.g., wading, fishing);
- Liquids (e.g., use of commercial products);
- Vapors/fumes (e.g., use of commercial products); and
- Indoors (e.g., carpets, floors, countertops).

The major factors that must be considered when estimating dermal exposure are: the chemical concentration in contact with the skin, the extent of skin surface area exposed, the duration of exposure, the absorption of the chemical through the skin, the internal dose, and the amount of chemical that can be delivered to a target organ (i.e., biologically effective dose) (see Figure 8-1). A detailed discussion of these factors can be found in Guidelines for Exposure Assessment (U.S. EPA, 1992a). This chapter focuses on measurements of body surface areas and dermal adherence of soil to the skin. *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992b), provides detailed information concerning dermal exposure assessment using a stepwise guide in the exposure assessment process.

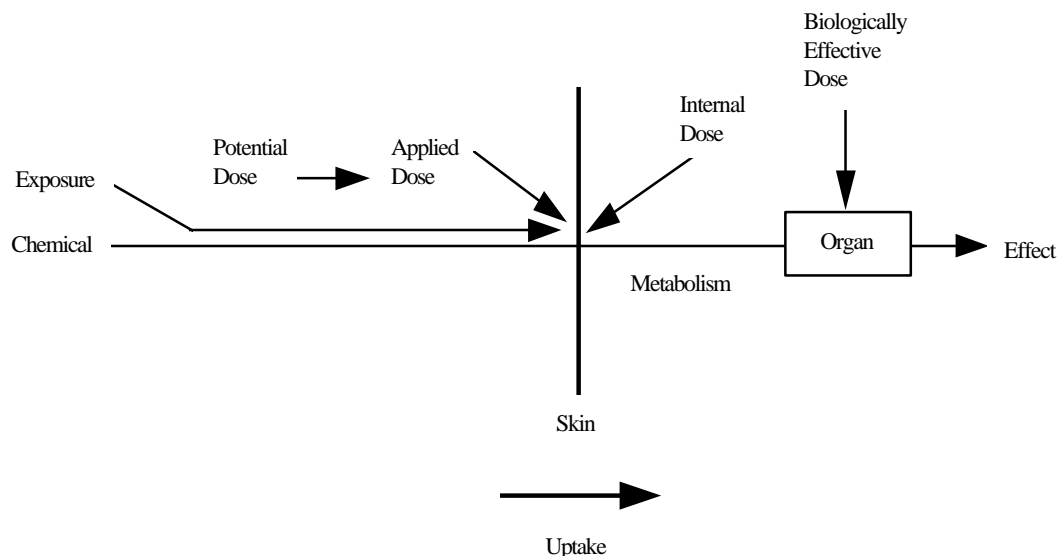


Figure 8-1. Schematic of Dose and Exposure: Dermal Route

Source: U.S. Environmental Protection Agency (1992a).

## 8.2 SURFACE AREA

### 8.2.1 Background

The total surface area of skin exposed to a contaminant must be determined using measurement or estimation techniques before conducting a dermal exposure assessment. Depending on the exposure scenario, estimation of the surface area for the total body or a specific body part can be used to calculate the contact rate for the pollutant. This section presents estimates for total body surface area and for body parts and presents information on the application of body surface area data.

### 8.2.2 Measurement Techniques

Coating, triangulation, and surface integration are direct measurement techniques that have been used to measure total body surface area and the surface area of specific body parts. Consideration has been given for differences due to age, gender, and race. The results of the various techniques have been summarized in *Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments* (U.S. EPA, 1985). The coating method consists of coating either the whole body or specific body regions with a substance of known or

1 measured area. Triangulation consists of marking the area of the body into geometric figures,  
2 then calculating the figure areas from their linear dimensions. Surface integration is performed by  
3 using a planimeter and adding the areas.

4 The triangulation measurement technique developed by Boyd (1935) has been found to be  
5 highly reliable. It estimates the surface area of the body using geometric approximations that  
6 assume parts of the body resemble geometric solids (Boyd, 1935). More recently, Pependorf and  
7 Leffingwell (1976), and Haycock et al. (1978) have developed similar geometric methods that  
8 assume body parts correspond to geometric solids, such as the sphere and cylinder. A linear  
9 method proposed by DuBois and DuBois (1916) is based on the principle that the surface areas of  
10 the parts of the body are proportional, rather than equal to the surface area of the solids they  
11 resemble.

12 In addition to direct measurement techniques, several formulae have been proposed to  
13 estimate body surface area from measurements of other major body dimensions (i.e., height and  
14 weight) (U.S. EPA, 1985). Generally, the formulae are based on the principles that body density  
15 and shape are roughly the same and that the relationship of surface area to any dimension may be  
16 represented by the curve of central tendency of their plotted values or by the algebraic expression  
17 for the curve. A discussion and comparison of formulae to determine total body surface area are  
18 presented in Appendix 8A.

### 20 **8.2.3 Body Surface Area Studies**

21 *U.S. EPA (1985) - Development of Statistical Distributions or Ranges of Standard*  
22 *Factors Used in Exposure Assessments* - U.S. EPA (1985) analyzed the direct surface area  
23 measurement data of Gehan and George (1970) using the Statistical Processing System (SPS)  
24 software package of Buhyoff et al. (1982). Gehan and George (1970) selected 401 measurements  
25 made by Boyd (1935) that were complete for surface area, height, weight, and age for their  
26 analysis. Boyd (1935) had reported surface area estimates for 1,114 individuals using coating,  
27 triangulation, or surface integration methods (U.S. EPA, 1985).

28 U.S. EPA (1985) used SPS to generate equations to calculate surface area as a function of  
29 height and weight. These equations were then used to calculate body surface area distributions of  
30 the U.S. population using the height and weight data obtained from the National Health and

1 Nutrition Examination Survey (NHANES) II and the computer program QNTLS of Rochon and  
2 Kalsbeek (1983).

3 The equation proposed by Gehan and George (1970) was determined by U.S. EPA (1985)  
4 to be the best choice for estimating total body surface area. However, the paper by Gehan and  
5 George (1970) gave insufficient information to estimate the standard error about the regression.  
6 Therefore, U.S. EPA (1985) used the 401 direct measurements of children and adults and  
7 reanalyzed the data using the formula of Dubois and Dubois (1916) and SPS to obtain the  
8 standard error (U.S. EPA, 1985).

9 Regression equations were developed specific body parts using the Dubois and Dubois  
10 (1916) formula and using the surface area of various body parts provided by Boyd (1935) and Van  
11 Graan (1969) in conjunction with SPS. Equations to estimate the body part surface area of  
12 children were not developed because of insufficient data.

13 Percentile estimates for total surface area of male and female children presented in  
14 Tables 8-1 and 8-2 were calculated using the total surface area regression equation, NHANES II  
15 height and weight data, and using QNTLS. Estimates are not included for children younger than  
16 2 years old because NHANES height data are not available for this age group. For children, the  
17 error associated with height and weight cannot be assumed to be zero because of their relatively  
18 small sizes. Therefore, the standard errors of the percentile estimates cannot be estimated, since it  
19 cannot be assumed that the errors associated with the exogenous variables (height and weight) are  
20 independent of that associated with the model; there are insufficient data to determine the  
21 relationship between these errors.

22 Measurements of the surface area of children's body parts are summarized as a percentage  
23 of total surface area in Table 8-3. Because of the small sample size, the data cannot be assumed  
24 to represent the average percentage of surface area by body part for all children. Note that the  
25 percent of total body surface area contributed by the head decreases from childhood to adult,  
26 while the percent contributed by the leg increases.

27 *Phillips et al. (1993) - Distributions of Total Skin Surface Area to Body Weight Ratios -*  
28 Phillips et al. (1993) observed a strong correlation (0.986) between body surface area and body  
29 weight and studied the effect of using these factors as independent variables in the LADD  
30 equation. Phillips et al. (1993) concluded that, because of the correlation between these two  
31 variables, the use of body surface area to body weight (SA/BW) ratios in human exposure

assessments is more appropriate than treating these factors as independent variables. Direct measurement (coating, triangulation, and surface integration) data from the scientific literature were used to calculate body surface area to body weight (SA/BW) ratios for two age groups of children (infants aged 0 to 2 years and children aged 2.1 to 17.9 years). These ratios were calculated by dividing body surface areas by corresponding body weights for the 401 individuals analyzed by Gehan and George (1970) and summarized by U.S. EPA (1985). Distributions of SA/BW ratios were developed and summary statistics were calculated for the two age groups and the combined data set. Summary statistics for the two children's age groups are presented in Table 8-4. The shapes of these SA/BW distributions were determined using D'Agostino's test. The results indicate that the SA/BW ratios for infants are lognormally distributed. SA/BW ratios for children were neither normally nor lognormally distributed. According to Phillips et al. (1993), SA/BW ratios should be used to calculate LADDs by replacing the body surface area factor in the numerator of the LADD equation with the SA/BW ratio and eliminating the body weight factor in the denominator of the LADD equation.

The effect of gender and age on SA/BW distribution was also analyzed by classifying the 401 observations by gender and age. Statistical analyses indicated no significant differences between SA/BW ratios for males and females. SA/BW ratios were found to decrease with increasing age.

*Wong et al. (2000) - Adult Proxy Responses to a Survey of Children's Dermal Soil Contact Activities* - Wong et al. (2000) conducted telephone surveys to gather information on children's activity patterns as related to dermal contact with soil during outdoor play on bare dirt or mixed grass and dirt surfaces. This study, the second Soil Contact Survey (SCS-II), was a follow-up to the initial Soil Contact Survey (SCS-I), conducted in 1996, that primarily focused on assessing adult behavior related to dermal contact with soil and dust (Garlock et al., 1999). As part of SCS-I, information was gathered on the behavior of children under the age of 18 years, however, the questions were limited to clothing choices and the length of time after soil contact to hand washing. Results obtained for children from SCS-I were not reported in Garlock et al. (1999), but some of the collected information is summarized in Wong et al (2000). Questions were posed for SCS-II to further define children's outdoor activities and hand washing and bathing frequency. For both soil contact surveys households were randomly phoned in order to

1 obtain nationally representative results. The adult respondents were questioned as surrogates for  
2 one randomly chosen child under the age of 18 residing within the household.

3 For SCS-I, the population size of children sampled was 211. Older children (those  
4 between the ages of 5 and 17) were questioned regarding participation in “gardening and  
5 yardwork,” “outdoor sports,” and “outdoor play activities.” For children less than 5 years old,  
6 “outdoor play activities” occurring on a playground or yard with “bare dirt or mixed grass and  
7 dirt” surfaces were noted. The clothing worn during these play activities during warm weather  
8 months (April through October) also was questioned. For both groups of children, information  
9 was gathered concerning hand washing, bathing, and clothes changing habits after soil contact  
10 activities, but these results are not reported in Wong et al. (2000).

11 Results of SCS-I indicate that most children wore short pants, a dress or skirt, short sleeve  
12 shirts, no socks, and leather or canvas shoes during the outdoor play activities of interest. Using  
13 data from Anderson et al. (1985) percentages of total body surface area associated with specific  
14 body parts were estimated (Table 8-5). Then exposed skin surface areas for children under age 5  
15 were estimated per clothing item as well as for all clothing items worn together during warm  
16 weather outdoor play (Table 8-6). Faces and hands were assumed to be exposed under all  
17 conditions with the face having a constant surface area fraction of 5 percent and the hands 6  
18 percent.

19 In the SCS-II, of 680 total adult respondents with a child in their household, 500 (73.5%)  
20 reported that their child played outdoors on bare dirt or mixed grass and dirt surfaces (identified  
21 as “players”). Those children that reportedly did not play outdoors (“non-players”) were  
22 typically very young ( $\leq 1$  year) or relatively older ( $\geq 14$  years). Of the 500 children that played  
23 outdoors, 497 played outdoors in warm weather months (April through October) and 390 were  
24 reported to play outdoors during cold weather months (November through March). These results  
25 are presented in Table 8-7. The frequency (days/week), duration (hours/day), and total hours per  
26 week spent playing outdoors was determined for those children identified as “players”  
27 (Table 8-8). The responses indicated that during the warmer months children spend a relatively  
28 high percentage of time outdoor and a lesser amount of time in cold weather. The median play  
29 frequency reported was 7 days/week in warm weather and 3 days/week in cold weather. Median  
30 play duration was 3 hours/day in warm weather and 1 hour/day during cold weather months.

Adult respondents were then questioned as to how many times per day their child washed his/her hands and how many times the child bathed or showered per week during both warm and cold weather months. This information provided an estimate of the time between skin contact with soil and removal of soil by washing (i.e., exposure time). Hand washing and bathing frequencies for child players are reported in Table 8-9. Based on these results, hand washing occurred a median of 4 times per day during both warm and cold weather months. The median frequency for baths and showers was estimated to be 7 times per week for both warm and cold weather.

Based on reported household incomes, the respondents sampled in SCS-II tended to have higher incomes than that of the general population. This may be explained by the fact that phone surveys cannot sample those households without telephones. Additional uncertainty or error in the study results may be presented by the use of surrogate respondents. Adult respondents were questioned regarding child activities that may have occurred in prior seasons, introducing the chance of recall error. In some instances, a respondent did not know the answer to a question or refused to answer. In Tables 8-10 and 8-11 information extracted from the National Human Activity Pattern Survey (NHAPS) (U.S. EPA, 1996). Table 8-10 compares mean play duration data from SCS-II to similar activities identified in NHAPS. The number of times per day a child washed his or her hands was presented in both SCS-II and NHAPS follow-up survey B and are shown in Table 8-11. Corresponding information for bathing frequency data collected from SCS-II was not collected in NHAPS. As indicated in Tables 8-10 and 8-11, where comparison is possible, NHAPS and SCS-II results showed similarities in observed behaviors.

#### **8.2.4 Application of Body Surface Area Data**

For swimming and bathing scenarios, past exposure assessments have assumed that 75 percent to 100 percent of the skin surface is exposed (U.S. EPA, 1992b). Central and upper-percentile values for children should be derived from Table 8-1 or 8-2.

Unlike exposure to liquids, clothing may or may not be effective in limiting the extent of exposure to soil. The children clothing scenarios are presented below.

**Central tendency mid range:** Child wears long sleeve shirt, pants, and shoes. The exposed skin surface is limited to the head and hands. Table 8-3 can be used to determine the skin surface area depending on the age group of interest.

**Upper percentile:** Child wears a short sleeve shirt, shorts, and shoes. The exposed skin surface is limited to the head, hands, forearms, and lower legs. Table 8-3 can be used to determine the skin surface area depending on the age group of interest.

The clothing scenarios presented above, suggest that roughly 10 percent to 25 percent of the skin area may be exposed to soil. Since some studies have suggested that exposure can occur under clothing, the upper end of this range was selected in *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992b) for deriving defaults. Default values for children can be derived by multiplying the 50th and 95th percentiles of the total surface area by 0.25 for the ages of interest.

When addressing soil contact exposures, assessors may want to refine estimates of surface area exposed on the basis of seasonal conditions. For example, in moderate climates, it may be reasonable to assume that 5 percent of the skin is exposed during the winter, 10 percent during the spring and fall, and 25 percent during the summer.

The previous discussion, has presented information about the area of skin exposed to soil. These estimates of exposed skin area should be useful to assessors using the traditional approach of multiplying the soil adherence factor by exposed skin area to estimate the total amount of soil on skin. The next section presents soil adherence data specific to activity and body part and is designed to be combined with the total surface area of that body part. No reduction of body part area is made for clothing coverage using this approach. Thus, assessors who adopt this approach, should not use the defaults presented above for soil exposed skin area. Rather, they should use Table 8-3 to estimate surface areas of specific body parts.

## **8.3 SOIL ADHERENCE TO SKIN**

### **8.3.1 Background**

Soil adherence to the surface of the skin is a required parameter to calculate dermal dose when the exposure scenario involves dermal contact with a chemical in soil. A number of studies have attempted to determine the magnitude of dermal soil adherence. These studies are described in detail in U.S. EPA (1992b). This section summarizes recent studies that estimate soil adherence to skin for use as exposure factors.

### 8.3.2 Soil Adherence to Skin Studies

*Kissel et al. (1996a) - Factors Affecting Soil Adherence to Skin in Hand-Press Trials: Investigation of Soil Contact and Skin Coverage* - Kissel et al. (1996a) conducted soil adherence experiments using five soil types (descriptor) obtained locally in the Seattle, Washington, area: sand (211), loamy sand (CP), loamy sand (85), sandy loam (228), and silt loam (72). All soils were analyzed by hydrometer (settling velocity) to determine composition. Clay contents ranged from 0.5 to 7.0 percent. Organic carbon content, determined by combustion, ranged from 0.7 to 4.6 percent. Soils were dry sieved to obtain particle size ranges of <150, 150-250, and >250  $\mu\text{m}$ . For each soil type, the amount of soil adhering to an adult female hand, using both sieved and unsieved soils, was determined by measuring the difference in soil sample weight before and after the hand was pressed into a pan containing the test soil. Loadings were estimated by dividing the recovered soil mass by total hand area, although loading occurred primarily on only one side of the hand. Results showed that generally, soil adherence to hands could be directly correlated with moisture content, inversely correlated with particle size, and independent of clay content or organic carbon content.

*Kissel et al. (1996b) - Field Measurement of Dermal Soil Loading Attributable to Various Activities: Implications for Exposure Assessment* - Further experiments were conducted by Kissel et al. (1996b) to estimate soil adherence associated with various indoor and outdoor activities: greenhouse gardening, tae kwon do karate, soccer, rugby, reed gathering, irrigation installation, truck farming, and playing in mud. Several of the activities studied by Kissel (1996b) involved children, as shown in Table 8-12. A summary of field studies by activity, gender, age, field conditions, and clothing worn is presented in Table 8-12. Subjects' body surfaces (forearms, hands, lower legs in all cases, faces, and/or feet; pairs in some cases) were washed before and after monitored activities. Paired samples were pooled into single ones. Mass recovered was converted to loading using allometric models of surface area. These data are presented in Table 8-13. Results presented are based on direct measurement of soil loading on the surfaces of skin before and after activities that may be expected to have soil contact (Kissel et al., 1996b). The results indicate that the rate of soil adherence to the hands is higher than for other parts of the body.

1           *Holmes, Jr., K.K., J.H. Shirai, K.Y. Richter, and J.C. Kissel (1999) - Field Measurement*  
2           *of Dermal Soil Loadings in Occupational and Recreational Activities - Holmes et al. (1999)*  
3           collected pre- and post-activity soil loadings on various body parts of individuals within groups  
4           engaged in various occupational and recreational activities. These groups included children at a  
5           daycare center and playing indoors in a residential setting. This study was conducted as a follow  
6           up to previous field sampling of soil adherence on individuals participating in various activities  
7           (Kissel et al., 1996). For this round of sampling, soil loading data were collected utilizing the  
8           same methods used and described in Kissel et al. (1996). Information regarding the groups of  
9           children studied and their observed activities are presented in Table 8-14.

10           The daycare children studied were all at one location and measurements were taken on  
11           three different days. The children freely played both indoors in the house and outdoors in the  
12           backyard. The backyard was described as having a grass lawn, shed, sand box, and wood chip  
13           box. In this setting, the children engaged in typical activities including: playing with toys and  
14           each other, wrestling, sleeping, and eating. The number of children within each day's group and  
15           the clothing worn is described in Table 8-15.

16           The five children measured on the first day were washed first thing in the morning to  
17           establish a preactivity level. They were next washed at noon to determine the postactivity soil  
18           loading for the morning (Daycare kids No. 1a). The same children were washed once again at the  
19           close of the day for measurement of soil adherence from the afternoon play activities (Daycare  
20           kids No. 1b).

21           For the second observation day (Daycare kids No. 2), postactivity data were collected for  
22           five children. All the activities on this day occurred indoors. For the third daycare group  
23           (Daycare kids No. 3), four children were studied.

24           On two separate days, children playing indoors in a home environment were monitored.  
25           The first group (Indoor kids No. 1) had four children while the second group (Indoor kids No. 2)  
26           had six children. The play area was described by Holmes et al. (1999) as being primarily carpeted.  
27           The clothing worn by the children within each day's group is described in Table 8-15.

28           The geometric means and standard deviations of the postactivity soil adherence for each  
29           group of children and for each body part are summarized in Table 8-16. According to Holmes et  
30           al. (1999), variations in the soil loading data from the daycare participants reflect differences in  
31           the weather and access to the outdoors.

1 An advantage of this study is that it provides a supplement to soil loading data collected in  
2 a previous round of studies (Kissel et al., 1996b). Also, the data support the assumption that  
3 hand loading can be used as a conservative estimate of soil loading on other body surfaces for the  
4 same activity. The activities studied represent normal child play both indoors and outdoors, as  
5 well as for different combinations of clothing. The small number of participants (*n*) is a  
6 disadvantage of this study. Also, the children studied and the activity setting may not be  
7 representative of the U.S. population.

8 *Kissel et al. (1998) - Investigation of Dermal Contact with Soil in Controlled Trials* - In  
9 this study, Kissel et al.(1998) measured dermal exposure to soil from staged activities conducted  
10 in a greenhouse. A fluorescent marker was mixed in soil so that soil contact for a particular skin  
11 surface area could be identified. As described in Kissel et al.(1998), the subjects, which included  
12 a group of children, were video imaged under a long-wave ultraviolet (UV) light before and after  
13 soil contact. In this manner, soil contact on hands, forearms, lower legs, and faces was assessed  
14 by presence of fluorescence. In addition to fluorometric data, gravimetric measurements for  
15 preactivity and postactivity were obtained from the different body parts examined.

16 The studied group of children played for 20 minutes in a soil bed of varying moisture  
17 content representing wet and dry soils. For wet soils, both combinations of long sleeves and long  
18 pants and short sleeves and short pants were tested. Children only wore short sleeves and short  
19 pants during play in the dry soil. Clothing was laundered after each trial. Thus, a total of three  
20 trials with children were conducted. The parameters describing each of these trials are  
21 summarized in Table 8-17.

22 Before each trial, each child was washed in order to obtain a preactivity or background  
23 gravimetric measurement. Preactivity data are shown in Table 8-18. Body part surface areas  
24 were calculated using Anderson et al. (1985) for the range of heights and weights of the study  
25 participants.

26 For wet soil, postactivity fluorescence results indicated that the hand had a much higher  
27 fractional coverage than other body surfaces (see Figure 8-2). No fluorescence was detected on  
28 the forearms or lower legs of children dressed in long sleeves and pants.

29 As shown in Figure 8-3, postactivity gravimetric measurements showed higher soil loading  
30 on hands and much lower amounts on other body surfaces, as was observed with fluorescence  
31 data. According to Kissel et al. (1998), the relatively low loadings observed on non-hand body

parts may be a result of the limited area of contact rather than lower localized loadings. A geometric mean dermal loading of 0.7 mg/cm<sup>2</sup> was found on children's hands following play in wet soil. Mean loadings were lower on hands in the dry soil trial and on lower legs, forearms, and faces in both the wet and dry soil trials. Higher loadings were observed for all body surfaces with the higher moisture content soils.

This report is valuable in showing soil loadings from soils of different moisture content and providing evidence that dermal exposure to soil is not uniform for various body surfaces. There is also some evidence from this study demonstrating the protective effect of clothing. Disadvantages of the study include a small number of study participants and a short activity duration. Also, no information is provided on the ages of the children involved in the study.

## **8.4 RECOMMENDATIONS**

### **8.4.1 Body Surface Area**

Body surface area estimates are based on direct measurements. Re-analysis of data collected by Boyd (1935) by several investigators (Gehan and George, 1970; U.S. EPA, 1985; Murray and Burmaster, 1992; Phillips et al., 1993) constitutes much of this literature. Methods are highly reproducible and the results are widely accepted. The representativeness of these data to the general population is somewhat limited since variability due to race or gender have not been systematically addressed.

The recommendations for body surface area for children are summarized in Table 8-19. These recommendations are based on U.S. EPA (1985) and Phillips et al. (1993). Table 8-20 presents the confidence ratings for various aspects of the recommendations for body surface area. The U.S. EPA (1985) study is based on generally accepted measurements that enjoy widespread usage, summarizes and compares previous reports in the literature, provides statistical distributions for adults, and provides data for total body surface area and body parts by gender for children. The results are based on selected measurements from the original data collected by Boyd (1935). Phillips et al. (1993) analyses are based on direct measurement data that provide distributions of body surface area to calculate LADD. The results are consistent with previous efforts to estimate body surface area. Analyses are also based on measurements selected from the original measurements made by Boyd (1935) and data were not analyzed for specific body parts.

#### 8.4.2 Soil Adherence to Skin

Recommendations for the rate of soil adherence to the skin are based on data collected by Kissel et al. (1996a; 1996b) for specific activities. The experimental design and measurement methods used by Kissel et al. (1996a; 1996b) are straightforward and reproducible, but it should be noted that the controlled experiments and field studies are based on a limited number of measurements and specific situations were selected to assess soil adherence to skin. Consequently, variation due to individuals, protective clothing, temporal, or seasonal factors remain to be studied in more detail. Therefore, caution is required in interpretation and application of these results for exposure assessments.

In consideration, of these general observations and the recent data from Kissel et al. (1996a, 1996b), changes are needed from past EPA recommendations which used one adherence value to represent all soils, body parts, and activities. One approach would be to select the activity from Table 8-12 which best represents the exposure scenario of concern and use the corresponding adherence value from Table 8-13. Although this approach represents an improvement, it still has shortcomings. For example, it is difficult to decide which activity in Table 8-13 is most representative of a typical residential setting involving a variety of activities. It may be useful to combine these activities into general classes of low, moderate, and high contact. In the future, it may be possible to combine activity-specific soil adherence estimates with survey-specific soil adherence estimates with survey-derived data on activity frequency and duration to develop overall average soil contact rates. EPA is sponsoring research to develop such an approach. As this information becomes available, updated recommendations will be issued.

Table 8-13 provides the best estimates available on activity-specific adherence values, but are based on limited data. Therefore, they have a high degree of uncertainty such that considerable judgment must be used when selecting them for an assessment. The confidence ratings for various aspects of this recommendation are summarized in Table 8-21. Insufficient data are available to develop a distribution or a probability function for soil loadings.

Past EPA guidance has recommended assuming that soil exposure occurs primarily to exposed body surfaces and used typical clothing scenarios to derive estimates of exposed skin area. The approach recommended above for estimating soil adherence addresses this issue in a different manner. This change was motivated by two developments. First, increased acceptance that soil and dust particles can get under clothing and be deposited on skin. Second, recent

1 studies of soil adherence have measured soil on entire body parts (whether or not they were  
2 covered by clothing) and averaged the amount of soil adhering to skin over the area of entire body  
3 part. The soil adherence levels resulting from these new studies must be combined with the  
4 surface area of the entire body part (not merely unclothed surface area) to estimate the amount of  
5 contaminant on skin. An important caveat, however, is that this approach assumes that clothing  
6 in the exposure scenario of interest matches the clothing in the studies used to derive these  
7 adherence levels such that the same degree of protection provided by clothing can be assumed in  
8 both cases. If clothing differs significantly between the studies reported here and the exposure  
9 scenarios under investigation, considerable judgment is needed to adjust either the adherence level  
10 or surface area assumption.

11 The dermal adherence value represents the amount of soil on the skin at the time of  
12 measurement. Assuming that the amount measured on the skin represents its accumulation  
13 between washings and that people wash at least once per day, these adherence values can be  
14 interpreted as daily contact rates (U.S. EPA, 1992b). However, this is not recommended because  
15 the residence time of soils on skin has not been studied. Instead, it is recommended that these  
16 adherence values be interpreted on an event basis (U.S. EPA, 1992b).

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Table 8-1. Total Body Surface Area of Male  
Children in Square Meters<sup>a</sup>

| Age<br>(yr) <sup>b</sup> | Percentile |       |       |       |       |       |       |       |       |
|--------------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|
|                          | 5          | 10    | 15    | 25    | 50    | 75    | 85    | 90    | 95    |
| 2 < 3                    | 0.527      | 0.544 | 0.552 | 0.569 | 0.603 | 0.629 | 0.643 | 0.661 | 0.682 |
| 3 < 4                    | 0.585      | 0.606 | 0.620 | 0.636 | 0.664 | 0.700 | 0.719 | 0.729 | 0.764 |
| 4 < 5                    | 0.633      | 0.658 | 0.673 | 0.689 | 0.731 | 0.771 | 0.796 | 0.809 | 0.845 |
| 5 < 6                    | 0.692      | 0.721 | 0.732 | 0.746 | 0.793 | 0.840 | 0.864 | 0.895 | 0.918 |
| 6 < 7                    | 0.757      | 0.788 | 0.809 | 0.821 | 0.866 | 0.915 | 0.957 | 1.01  | 1.06  |
| 7 < 8                    | 0.794      | 0.832 | 0.848 | 0.877 | 0.936 | 0.993 | 1.01  | 1.06  | 1.11  |
| 8 < 9                    | 0.836      | 0.897 | 0.914 | 0.932 | 1.00  | 1.06  | 1.12  | 1.17  | 1.24  |
| 9 < 10                   | 0.932      | 0.966 | 0.988 | 1.00  | 1.07  | 1.13  | 1.16  | 1.25  | 1.29  |
| 10 < 11                  | 1.01       | 1.04  | 1.06  | 1.10  | 1.18  | 1.28  | 1.35  | 1.40  | 1.48  |
| 11 < 12                  | 1.00       | 1.06  | 1.12  | 1.16  | 1.23  | 1.40  | 1.47  | 1.53  | 1.60  |
| 12 < 13                  | 1.11       | 1.13  | 1.20  | 1.25  | 1.34  | 1.47  | 1.52  | 1.62  | 1.76  |
| 13 < 14                  | 1.20       | 1.24  | 1.27  | 1.30  | 1.47  | 1.62  | 1.67  | 1.75  | 1.81  |
| 14 < 15                  | 1.33       | 1.39  | 1.45  | 1.51  | 1.61  | 1.73  | 1.78  | 1.84  | 1.91  |
| 15 < 16                  | 1.45       | 1.49  | 1.52  | 1.60  | 1.70  | 1.79  | 1.84  | 1.90  | 2.02  |
| 16 < 17                  | 1.55       | 1.59  | 1.61  | 1.66  | 1.76  | 1.87  | 1.98  | 2.03  | 2.16  |
| 17 < 18                  | 1.54       | 1.56  | 1.62  | 1.69  | 1.80  | 1.91  | 1.96  | 2.03  | 2.09  |
| 3 < 6                    | 0.616      | 0.636 | 0.649 | 0.673 | 0.728 | 0.785 | 0.817 | 0.842 | 0.876 |
| 6 < 9                    | 0.787      | 0.814 | 0.834 | 0.866 | 0.931 | 1.01  | 1.05  | 1.09  | 1.14  |
| 9 < 12                   | 0.972      | 1.00  | 1.02  | 1.07  | 1.16  | 1.28  | 1.36  | 1.42  | 1.52  |
| 12 < 15                  | 1.19       | 1.24  | 1.27  | 1.32  | 1.49  | 1.64  | 1.73  | 1.77  | 1.85  |
| 15 < 18                  | 1.50       | 1.55  | 1.59  | 1.65  | 1.75  | 1.86  | 1.94  | 2.01  | 2.11  |

<sup>a</sup>Lack of height measurements for children <2 years in NHANES II precluded calculation of surface areas for this age group.

<sup>b</sup>Estimated values calculated using NHANES II data.

Source: U.S. Environmental Protection Agency (1985).

Table 8-2. Total Body Surface Area of Female  
Children in Square Meters<sup>a</sup>

| Percentile            |       |       |       |       |       |       |       |       |       |  |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--|
| Age (yr) <sup>b</sup> | 5     | 10    | 15    | 25    | 50    | 75    | 85    | 90    | 95    |  |
| 2 < 3                 | 0.516 | 0.532 | 0.544 | 0.557 | 0.579 | 0.610 | 0.623 | 0.637 | 0.653 |  |
| 3 < 4                 | 0.555 | 0.570 | 0.589 | 0.607 | 0.649 | 0.688 | 0.707 | 0.721 | 0.737 |  |
| 4 < 5                 | 0.627 | 0.639 | 0.649 | 0.666 | 0.706 | 0.758 | 0.777 | 0.794 | 0.820 |  |
| 5 < 6                 | 0.675 | 0.700 | 0.714 | 0.735 | 0.779 | 0.830 | 0.870 | 0.902 | 0.952 |  |
| 6 < 7                 | 0.723 | 0.748 | 0.770 | 0.791 | 0.843 | 0.914 | 0.961 | 0.989 | 1.03  |  |
| 7 < 8                 | 0.792 | 0.808 | 0.819 | 0.854 | 0.917 | 0.977 | 1.02  | 1.06  | 1.13  |  |
| 8 < 9                 | 0.863 | 0.888 | 0.913 | 0.932 | 1.00  | 1.05  | 1.08  | 1.11  | 1.18  |  |
| 9 < 10                | 0.897 | 0.948 | 0.969 | 1.01  | 1.06  | 1.14  | 1.22  | 1.31  | 1.41  |  |
| 10 < 11               | 0.981 | 1.01  | 1.05  | 1.10  | 1.17  | 1.29  | 1.34  | 1.37  | 1.43  |  |
| 11 < 12               | 1.06  | 1.09  | 1.12  | 1.16  | 1.30  | 1.40  | 1.50  | 1.56  | 1.62  |  |
| 12 < 13               | 1.13  | 1.19  | 1.24  | 1.27  | 1.40  | 1.51  | 1.62  | 1.64  | 1.70  |  |
| 13 < 14               | 1.21  | 1.28  | 1.32  | 1.38  | 1.48  | 1.59  | 1.67  | 1.75  | 1.86  |  |
| 14 < 15               | 1.31  | 1.34  | 1.39  | 1.45  | 1.55  | 1.66  | 1.74  | 1.76  | 1.88  |  |
| 15 < 16               | 1.38  | 1.49  | 1.43  | 1.47  | 1.57  | 1.67  | 1.72  | 1.76  | 1.83  |  |
| 16 < 17               | 1.40  | 1.46  | 1.48  | 1.53  | 1.60  | 1.69  | 1.79  | 1.84  | 1.91  |  |
| 17 < 18               | 1.42  | 1.49  | 1.51  | 1.56  | 1.63  | 1.73  | 1.80  | 1.84  | 1.94  |  |
| 3 < 6                 | 0.585 | 0.610 | 0.630 | 0.654 | 0.711 | 0.770 | 0.808 | 0.831 | 0.879 |  |
| 6 < 9                 | 0.754 | 0.790 | 0.804 | 0.845 | 0.919 | 1.00  | 1.04  | 1.07  | 1.13  |  |
| 9 < 12                | 0.957 | 0.990 | 1.03  | 1.06  | 1.16  | 1.31  | 1.38  | 1.43  | 1.56  |  |
| 12 < 15               | 1.21  | 1.27  | 1.30  | 1.37  | 1.48  | 1.61  | 1.68  | 1.74  | 1.82  |  |
| 15 < 18               | 1.40  | 1.44  | 1.47  | 1.51  | 1.60  | 1.70  | 1.76  | 1.82  | 1.92  |  |

<sup>a</sup>Lack of height measurements for children <2 years in NHANES II precluded calculation of surface areas for this age group.

<sup>b</sup>Estimated values calculated using NHANES II data.

Source: U.S. EPA (1985).

Table 8-3. Percentage of Total Body Surface Area by Body Part For Children

| Age<br>(yr) | N<br>M:F | Percent of Total |           |       |           |      |           |       |           |      |           |      |           |
|-------------|----------|------------------|-----------|-------|-----------|------|-----------|-------|-----------|------|-----------|------|-----------|
|             |          | Head             |           | Trunk |           | Arms |           | Hands |           | Legs |           | Feet |           |
|             |          | Mean             | Min-Max   | Mean  | Min-Max   | Mean | Min-Max   | Mean  | Min-Max   | Mean | Min-Max   | Mean | Min-Max   |
| < 1         | 2:0      | 18.2             | 18.2-18.3 | 35.7  | 34.8-36.6 | 13.7 | 12.4-15.1 | 5.3   | 5.21-5.39 | 20.6 | 18.2-22.9 | 6.54 | 6.49-6.59 |
| 1 < 2       | 1:1      | 16.5             | 16.5-16.5 | 35.5  | 34.5-36.6 | 13.0 | 12.8-13.1 | 5.68  | 5.57-5.78 | 23.1 | 22.1-24.0 | 6.27 | 5.84-6.70 |
| 2 < 3       | 1:0      | 14.2             |           | 38.5  |           | 11.8 |           | 5.30  |           | 23.2 |           | 7.07 |           |
| 3 < 4       | 0:5      | 13.6             | 13.3-14.0 | 31.9  | 29.9-32.8 | 14.4 | 14.2-14.7 | 6.07  | 5.83-6.32 | 26.8 | 26.0-28.6 | 7.21 | 6.80-7.88 |
| 4 < 5       | 1:3      | 13.8             | 12.1-15.3 | 31.5  | 30.5-32.4 | 14.0 | 13.0-15.5 | 5.70  | 5.15-6.62 | 27.8 | 26.0-29.3 | 7.29 | 6.91-8.10 |
| 5 < 6       |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 6 < 7       | 1:0      | 13.1             |           | 35.1  |           | 13.1 |           | 4.71  |           | 27.1 |           | 6.90 |           |
| 7 < 8       |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 8 < 9       |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 9 < 10      | 0:2      | 12.0             | 11.6-12.5 | 34.2  | 33.4-34.9 | 12.3 | 11.7-12.8 | 5.30  | 5.15-5.44 | 28.7 | 28.5-28.8 | 7.58 | 7.38-7.77 |
| 10 < 11     |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 11 < 12     |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 12 < 13     | 1:0      | 8.74             |           | 34.7  |           | 13.7 |           | 5.39  |           | 30.5 |           | 7.03 |           |
| 13 < 14     | 1:0      | 9.97             |           | 32.7  |           | 12.1 |           | 5.11  |           | 32.0 |           | 8.02 |           |
| 14 < 15     |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 15 < 16     |          |                  |           |       |           |      |           |       |           |      |           |      |           |
| 16 < 17     | 1:0      | 7.96             |           | 32.7  |           | 13.1 |           | 5.68  |           | 33.6 |           | 6.93 |           |
| 17 < 18     | 1:0      | 7.58             |           | 31.7  |           | 17.5 |           | 5.13  |           | 30.8 |           | 7.28 |           |

N: Number of subjects, male to female ratios.

Source: U.S. EPA (1985).

Table 8-4. Descriptive Statistics For Surface Area/body Weight (SA/BW) Ratios (m<sup>2</sup>/kg)

| Age (yrs.) | Mean   | Range<br>Min-Max | SD <sup>a</sup> | SE <sup>b</sup> | Percentiles |        |        |        |        |        |        |
|------------|--------|------------------|-----------------|-----------------|-------------|--------|--------|--------|--------|--------|--------|
|            |        |                  |                 |                 | 5           | 10     | 25     | 50     | 75     | 90     | 95     |
| 0-2        | 0.0641 | 0.0421-0.1142    | 0.0114          | 7.84e-4         | 0.0470      | 0.0507 | 0.0563 | 0.0617 | 0.0719 | 0.0784 | 0.0846 |
| 2.1 - 17.9 | 0.0423 | 0.0268-0.0670    | 0.0076          | 1.05e-3         | 0.0291      | 0.0328 | 0.0376 | 0.0422 | 0.0454 | 0.0501 | 0.0594 |

<sup>a</sup>Standard deviation.

<sup>b</sup>Standard error of the mean.

Source: Phillips et al. (1993).

Table 8-5. Clothing choices and assumed body surface areas exposed

| Clothing response   | Area assumed exposed                      | % of total body surface area <sup>a</sup> |     |
|---------------------|---|---|-----|
|                     |   | M   | F   |
| Long pants          |   | 0   | 0   |
| Short pants         | lower ½ of thigh and upper ½ of lower leg | 13  | 13  |
| Long sleeves        |   | 0   | 0   |
| Short sleeves       | forearms                                  | 6   | 6   |
| No shirt (males)    | ¾ trunk and arms                          | 38  | n/a |
| Halter (females)    | ½ trunk and arms                          | n/a                                       | 30  |
| High socks          |   | 0   | 0   |
| Low socks           | 1/4 lower leg                             | 3   | 3   |
| No socks            | bottom half lower leg                     | 6   | 6   |
| Shoes               |   | 0   | 0   |
| No shoes or sandals | feet                                      | 7   | 7   |
| Gloves              |   | 0   | 0   |
| No gloves           | hands                                     | 6   | 6   |
| Hat or no hat       | 1/3 head for face                         | 5   | 5   |
| Maximum exposure    |   | 75  | 67  |

a After Anderson et. al (1985).

Table 8-6. Estimated skin surface exposed during warm weather outdoor play for children under age 5 (based on SCS-I data).

|        | Skin area exposed (% of total) based on expressed choice of |               |       |       |                  |              |
|--------|---|---------------|-------|-------|------------------|--------------|
|        | pants   | shirt sleeves | socks | shoes | hat <sup>a</sup> | all clothing |
| n      | 41  | 43            | 42    | 43    | 43               | 41           |
| Mean   | 12.8  | 6.6           | 4.4   | 3.0   | 5.0              | 32.0         |
| Median | 13.0  | 6.0           | 5.3   | 3.5   | 5.0              | 30.5         |
| S.D.   | 1.0   | 2.7           | 1.7   | 3.2   | 0.0              | 6.0          |

a Face was assumed to always be exposed.

Table 8-7. Number and percentage of respondents with children and those reporting outdoor play<sup>a</sup> activities in both warm and cold weather

|                   | Respondents<br>with children | Child players <sup>a</sup> |      | Child non players |      | Warm<br>weather<br>palyer <sup>b</sup> | Cold weather<br>player | Player in both<br>seasons |
|-------------------|------------------------------|----------------------------|------|-------------------|------|--|------------------------|---------------------------|
|                   | n                            | n                          | %    | n                 | %    | n                                      | n                      | %                         |
| SCS-II base       | 197                          | 128                        | 65.0 | 69                | 35.0 | 127                                    | 100                    | 50.8                      |
| SCS-II oversample | 483                          | 372                        | 77.0 | 111               | 23.0 | 370                                    | 290                    | 60.0                      |
| Total             | 680                          | 500                        | 73.5 | 180               | 26.5 | 497                                    | 390                    | 57.4                      |

a "Play" and "player" refer specifically to participation in outdoor play on bare dirt or mixed grass and dirt.

b Does not include three "Don't know/refused" responses regarding warm weather play.

Table 8-8. Play frequency and duration for all child players (from SCS-II data)

|                             | Cold weather        |                     |                   | Warm weather        |                     |                   |
|-----------------------------|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|
|                             | Frequency<br>(d/wk) | Duration<br>(hrs/d) | Total<br>(hrs/wk) | Frequency<br>(d/wk) | Duration<br>(hrs/d) | Total<br>(hrs/wk) |
| n                           | 372                 | 374                 | 373               | 488                 | 479                 | 480               |
| 5 <sup>th</sup> Percentile  | 1                   | 1                   | 1                 | 2                   | 1                   | 4                 |
| 50 <sup>th</sup> Percentile | 3                   | 1                   | 5                 | 7                   | 3                   | 20                |
| 95 <sup>th</sup> Percentile | 7                   | 4                   | 20                | 7                   | 8                   | 50                |

Table 8-9. Hand washing and bathing frequency for all child players (from SCS-II data)

|                             | Cold weather              |                       | Warm weather              |                       |
|-----------------------------|---------------------------|-----------------------|---------------------------|-----------------------|
|                             | Hand washing<br>(times/d) | Bathing<br>(times/wk) | Hand washing<br>(times/d) | Bathing<br>(times/wk) |
| n                           | 329                       | 388                   | 433                       | 494                   |
| 5 <sup>th</sup> Percentile  | 2                         | 2                     | 2                         | 3                     |
| 50 <sup>th</sup> Percentile | 4                         | 7                     | 4                         | 7                     |
| 95 <sup>th</sup> Percentile | 10                        | 10                    | 12                        | 14                    |

Table 8-10. NHAPS and SCS-II play duration<sup>a</sup> comparison

|        | Mean play duration<br>(min/d) |              |       | X <sup>2</sup> test <sup>b</sup> |
|--------|-------------------------------|--------------|-------|----------------------------------|
|        | Cold weather                  | Warm weather | Total | p<0.0001                         |
| NHAPS  | 114                           | 109          | 223   |                                  |
| SCS-II | 102                           | 206          | 308   |                                  |

a. Selected previous day activities in NHAPS, average day outdoor play on bare dirt or mixed grass and dirt in SCS-II.

b. 2x2 Chi-square test for contingency between NHAPS and SCS-II.

Table 8-11. NHAPS and SCS-II hand wash frequency comparison

|        |        | Percent reporting frequency (times/d) of: |     |     |     |       |       |     |              | X <sup>2</sup> test <sup>c</sup> |
|--------|--------|---|-----|-----|-----|-------|-------|-----|--------------|----------------------------------|
|        | Season | 0   | 1-2 | 3-5 | 6-9 | 10-19 | 20-29 | 30+ | “Don’t know” |                                  |
| NHAPS  | cold   | 3   | 18  | 51  | 17  | 7     | 1     | 1   | 3            | p = 0.06                         |
| SCS-II | cold   | 1   | 16  | 50  | 11  | 7     | 1     | 0   | 15           |                                  |
| NHAPS  | warm   | 3   | 18  | 51  | 15  | 7     | 2     | 1   | 4            | p = 0.001                        |
| SCS-II | warm   | 0   | 12  | 46  | 16  | 10    | 1     | 0   | 13           |                                  |

Table 8-12. Summary of Field Studies

| Activity            | Month | Event <sup>a</sup><br>(hrs) | N <sup>b</sup> | M | F | Age<br>(yrs) | Conditions  | Clothing  |
|---------------------|-------|-----------------------------|----------------|---|---|--------------|---|---|
| <u>Indoor</u>       |       |                             |                |   |   |              |   |   |
| Tae Kwon Do         | Feb.  | 1.5                         | 7              | 6 | 1 | 8-42         | Carpeted floor  | All in long-sleeve-long pants martial arts uniform, sleeves rolled back, barefoot               |
| Indoor Kids No. 1   | Jan.  | 2                           | 4              | 3 | 1 | 6-13         | Playing on carpeted floor   | 3 of 4 short pants, 2 of 4 short sleeves, socks, no shoes                                       |
| Indoor Kids No. 2   | Feb.  | 2                           | 6              | 4 | 2 | 3-13         | Playing on carpeted floor   | 5 of 6 long pants, 5 of 6 long sleeves, socks, no shoes   |
| Daycare Kids No. 1a | Aug.  | 3.5                         | 6              | 5 | 1 | 1-6.5        | Indoors: linoleum surface; outdoors: grass, bare earth, barked area | 4 of 6 in long pants, 4 of 6 short sleeves, shoes   |
| Daycare Kids No. 1b | Aug.  | 4                           | 6              | 5 | 1 | 1-6.5        | Indoors: linoleum surface; outdoors: grass, bare earth, barked area | 4 of 6 in long pants, 4 of 6 short sleeves, no shoes  |
| Daycare Kids No. 2c | Sept. | 8                           | 5              | 4 | 1 | 1-4          | Indoors, low napped carpeting, linoleum surfaces                    | 4 of 5 long pants, 3 of 5 long sleeves, all barefoot for part of the day                        |
| Daycare Kids No. 3  | Nov.  | 8                           | 4              | 3 | 1 | 1-4.5        | Indoors: linoleum surface, outside: grass, bare earth, barked area  | All long pants, 3 of 4 long sleeves, socks and shoes  |
| <u>Outdoor</u>      |       |                             |                |   |   |              |   |   |
| Soccer No. 1        | Nov.  | 0.67                        | 8              | 8 | 0 | 13-15        | Half grass-half bare earth  | 6 of 8 long sleeves, 4 of 8 long pants, 3 of 4 short pants and shin guards                      |
| Gardeners No. 1     | Aug.  | 4                           | 8              | 1 | 7 | 16-35        | Weeding, pruning, digging a trench                                  | 6 of 8 long pants, 7 of 8 short sleeves, 1 sleeveless, socks, shoes, intermittent use of gloves |
| Archeologists       | July  | 11.5                        | 7              | 3 | 4 | 16-35        | Digging with trowel, screening dirt, sorting                        | 6 of 7 short pants, all short sleeves, 3 no shoes or socks, 2 sandals                           |
| Kids-in-mud No. 1   | Sept. | 0.17                        | 6              | 5 | 1 | 9-14         | Lake shoreline  | All in short sleeve T-shirts, shorts, barefoot  |
| Kids-in-mud No. 2   | Sept. | 0.33                        | 6              | 5 | 1 | 9-14         | Lake shoreline  | All in short sleeve T-shirts, shorts, barefoot  |

<sup>a</sup>Event duration

<sup>b</sup>Number of subject

<sup>c</sup>Activities were confined to the house

Sources: Kissel et al. (1996b); Holmes et al. (1996).

Table 8-13. Geometric Mean And Geometric Standard Deviations of  
Soil Adherence by Activity And Body Region

| Activity            | N <sup>a</sup> | Post-activity Dermal Soil Loadings (mg/cm2) |               |               |              |               |
|---------------------|----------------|---|---------------|---------------|--------------|---------------|
|                     |                | Hands                                       | Arms          | Legs          | Faces        | Feet          |
| <u>Indoor</u>       |                |   |               |               |              |               |
| Tae Kwon Do         | 7              | 0.0063<br>1.9                               | 0.0019<br>4.1 | 0.0020<br>2.0 |              | 0.0022<br>2.1 |
| Indoor Kids No. 1   | 4              | 0.0073<br>1.9                               | 0.0042<br>1.9 | 0.0041<br>2.3 |              | 0.012<br>1.4  |
| Indoor Kids No. 2   | 6              | 0.014<br>1.5                                | 0.0041<br>2.0 | 0.0031<br>1.5 |              | 0.0091<br>1.7 |
| Daycare Kids No. 1a | 6              | 0.11<br>1.9                                 | 0.026<br>1.9  | 0.030<br>1.7  |              | 0.079<br>2.4  |
| Daycare Kids No. 1b | 6              | 0.15<br>2.1                                 | 0.031<br>1.8  | 0.023<br>1.2  |              | 0.13<br>1.4   |
| Daycare Kids No. 2  | 5              | 0.073<br>1.6                                | 0.023<br>1.4  | 0.011<br>1.4  |              | 0.044<br>1.3  |
| Daycare Kids No. 3  | 4              | 0.036<br>1.3                                | 0.012<br>1.2  | 0.014<br>3.0  |              | 0.0053<br>5.1 |
| <u>Outdoor</u>      |                |   |               |               |              |               |
| Soccer No. 1        | 8              | 0.11<br>1.8                                 | 0.011<br>2.0  | 0.031<br>3.8  | 0.012<br>1.5 |               |
| Gardeners No. 1     | 8              | 0.20<br>1.9                                 | 0.050<br>2.1  | 0.072<br>--   | 0.058<br>1.6 | 0.17<br>--    |
| Archeologists       | 7              | 0.14<br>1.3                                 | 0.041<br>1.9  | 0.028<br>4.1  | 0.050<br>1.8 | 0.24<br>1.4   |
| Kids-in-mud No. 1   | 6              | 35<br>2.3                                   | 11<br>6.1     | 36<br>2.0     |              | 24<br>3.6     |
| Kids-in-mud No. 2   | 6              | 58<br>2.3                                   | 11<br>3.8     | 9.5<br>2.3    |              | 6.7<br>12.4   |

<sup>a</sup>Number of subjects.

Sources: Kissel et al. (1996b); Holmes et al. (1996).

Table 8-14. Summary of Groups Assayed in Round 2 of Field Measurements

| Activity            | Month | Event <sup>a</sup> (hrs) | <i>n</i> <sup>b</sup> | Males | Females | Ages    |
|---------------------|-------|--------------------------|-----------------------|-------|---------|---------|
| Daycare kids No. 1a | Aug.  | 3.5                      | 6                     | 5     | 1       | 1 - 6.5 |
| Daycare kids No. 1b | Aug.  | 4                        | 6                     | 5     | 1       | 1 - 6.5 |
| Daycare kids No. 2  | Sept. | 8                        | 5                     | 4     | 1       | 1 - 4   |
| Daycare kids No. 3  | Nov.  | 8                        | 4                     | 3     | 1       | 1 - 4.5 |
| Indoor kids No. 1   | Jan.  | 2                        | 4                     | 3     | 1       | 6 - 13  |
| Indoor kids No. 2   | Feb.  | 2                        | 6                     | 4     | 2       | 3 - 13  |

a Event duration.

b Number of subjects.

Table 8-15. Attire for Individuals within Children's Groups Studied

| Activity                        | <i>n</i> <sup>a</sup> | Pants |       | Sleeves |       | Socks |     | Shoes  |
|---------------------------------|-----------------------|-------|-------|---------|-------|-------|-----|--|
|                                 |                       | Long  | Short | Long    | Short | High  | Low |  |
| Daycare kids No. 1a             | 6                     | 4     | 2     | 1       | 5     | 1     | 5   | low leather or canvas shoes - 6                          |
| Daycare kids No. 1b             | 6                     | 4     | 2     | 1       | 5     | 1     | 5   | barefoot - 3<br>low leather or canvas shoes - 3          |
| Daycare kids No. 2              | 5                     | 4     | 1     | 2       | 3     | NA    | NA  | barefoot - 2<br>shoes/socks ½ day and barefoot ½ day - 3 |
| Daycare kids No. 3 <sup>b</sup> | 4                     | 4     | 0     | 3       | 1     | 0     | 4   | low shoes - 4  |
| Indoor kids No. 1               | 4                     | 1     | 3     | 2       | 2     | 0     | 4   | no shoes (socks only) - 4                                |
| Indoor kids No. 2               | 6                     | 5     | 1     | 5       | 1     | 0     | 6   | no shoes (socks only) - 6                                |

a Number of subjects.

b All children wore jackets when engaged in outdoor activities.

NA - "Not Available": 3 children wore socks for ½ day in the morning but no specific information is provided on the type of socks worn.

Table 8-16. Geometric Means (Geometric Standard Deviations) of Round 2 Post-activity Loadings

| Activity            | <i>n</i> <sup>a</sup> | Postactivity Dermal Soil Loadings (mg/cm <sup>2</sup> ) |              |              |                    |              |
|---------------------|-----------------------|---|--------------|--------------|--------------------|--------------|
|                     |                       | Hands   | Forearms     | Lower legs   | Faces <sup>b</sup> | Feet         |
| Daycare kids No. 1a | 4                     | 0.11 (1.9)  | 0.026 (1.9)  | 0.030 (1.7)  |                    | 0.079 (2.4)  |
| Daycare kids No. 1b | 6                     | 0.15 (2.1)  | 0.031 (1.8)  | 0.023 (1.2)  |                    | 0.13 (1.4)   |
| Daycare kids No. 2  | 6                     | 0.073 (1.6)   | 0.023 (1.4)  | 0.011 (1.4)  |                    | 0.044 (1.3)  |
| Daycare kids No. 3  | 6                     | 0.036 (1.3)   | 0.012 (1.2)  | 0.014 (3.0)  |                    | 0.0053 (5.1) |
| Indoor kids No. 1   | 5                     | 0.0073 (1.9)  | 0.0042 (1.9) | 0.0041 (2.3) |                    | 0.012 (1.4)  |
| Indoor kids No. 2   | 4                     | 0.014 (1.5)   | 0.0041 (2.0) | 0.0031 (1.5) |                    | 0.0091 (1.7) |

a Number of subjects (number of data points for specific non-hand body parts may deviate slightly).

b Children's feet rather than faces were washed in order to reduce the chance of a child's refusal to participate.

Table 8-17. Summary of Controlled Green House Trials - Children Playing

| Activity | Ages | Duration<br>(min) | Soil moisture<br>(%) | Clothing <sup>a</sup> | n | Male | Female |
|----------|------|-------------------|----------------------|-----------------------|---|------|--------|
| Playing  | 8-12 | 20                | 17-18                | L                     | 4 | 3    | 1      |
|          |      |                   | 16-18                | S                     | 9 | 5    | 4      |
|          |      |                   | 3-4                  | S                     | 5 | 3    | 2      |

a L, long sleeves and long pants; S, short sleeves and short pants.

Table 8-18. Preactivity Loadings Recovered from Greenhouse Trial Children Volunteers

| Area       | n  | Body part surface area (cm <sup>2</sup> ) | Geometric mean<br>(95% C.I.) (µg/cm <sup>2</sup> ) |
|------------|----|---|--|
| Hands      | 12 | 420-798                                   | 9.4<br>(5.4 - 15.8)                                |
| Forearms   | 12 | 584-932                                   | 3.4<br>(2.3 - 5.2)                                 |
| Lower legs | 12 | 1,206-2,166                               | 1.0<br>(0.7 - 1.5)                                 |
| Face       | 12 | 388-602                                   | 0.8<br>(0.5 - 1.5)                                 |

Figure 8-2. Skin Coverage as Determined by Fluorescence vs. Body Part for Adults Transplanting Plants and for Children Playing in Wet Soils

Figure 8-3. Gravimetric Loading vs. Body Part for Adult Transplanting Plants in Wet Soil and for Children Playing in Wet and Dry Soils

Table 8-19. Summary of Recommended Values For Skin Surface Area

| Surface Area | Central Tendency | Upper Percentile             | Multiple Percentiles         |
|--------------|------------------|------------------------------|------------------------------|
| Whole body   | ---              | see Tables 8-1, 8-2, and 8-4 | see Tables 8-1, 8-2, and 8-4 |
| Body parts   | ---              | see Table 8-3                | see Table 8-3                |

Table 8-20. Confidence in Body Surface Area Measurement Recommendations

| Considerations                         | Rationale   | Rating        |
|--|---|---------------|
| <b>Study Elements</b>                  |   |               |
| • Level of Peer Review                 | Studies were from peer reviewed journal articles. EPA report was peer reviewed before distribution.   | High          |
| • Accessibility                        | The journals used have wide circulation. EPA report available from National Technical Information Service.  | High          |
| • Reproducibility                      | Experimental methods are well-described.  | High          |
| • Focus on factor of interest          | Experiments measured skin area directly.  | High          |
| • Data pertinent to U.S.               | Experiments conducted in the U.S.   | High          |
| • Primary data                         | Re-analysis of primary data in more detail by two different investigators .   | Low           |
| • Currency                             | Neither rapidly changing nor controversial area; estimates made in 1935 deemed to be accurate and subsequently used by others.                            | Low           |
| • Adequacy of data collection period   | Not relevant to exposure factor; parameter not time dependent.  | NA            |
| • Validity of approach                 | Approach used by other investigators; not challenged in other studies.  | High          |
| • Representativeness of the population | Not statistically representative of U.S. population.  | Medium        |
| • Characterization of variability      | Individual variability due to age, race, or gender not studied.   | Low           |
| • Lack of bias in study design         | Objective subject selection and measurement methods used; results reproduced by others with different methods.  | High          |
| • Measurement error                    | Measurement variations are low; adequately described by normal statistics.  | Low/Medium    |
| <b>Other Elements</b>                  |   |               |
| • Number of studies                    | 1 experiment; two independent re-analyses of this data set.   | Medium        |
| • Agreement among researchers          | Consistent results obtained with different analyses; but from a single set of measurements.   | Medium        |
| <b>Overall Rating</b>                  | This factor can be directly measured. It is not subject to dispute. Influence of age, race, or gender have not been detailed adequately in these studies. | <b>Medium</b> |

Table 8-21. Confidence in Soil Adherence to Skin Recommendations

| Considerations                         | Rationale   | Rating     |
|--|---|------------|
| <b>Study Elements</b>                  |   |            |
| • Level of Peer Review                 | Studies were from peer reviewed journal articles.   | High       |
| • Accessibility                        | Articles were published in widely circulated journals.  | High       |
| • Reproducibility                      | Reports clearly describe experimental method.   | High       |
| • Focus on factor of interest          | The goal of the studies was to determine soil adherence to skin.  | High       |
| • Data pertinent to U.S.               | Experiments were conducted in the U.S.  | High       |
| • Primary data                         | Experiments were directly measure soil adherence to skin; exposure and dose of chemicals in soil were measured indirectly or estimated from soil contact. | High       |
| • Currency                             | New studies were presented.   | High       |
| • Adequacy of data collection period   | Seasonal factors may be important, but have not been studied adequately.  | Medium     |
| • Validity of approach                 | Skin rinsing technique is a widely employed procedure.  | High       |
| • Representativeness of the population | Studies were limited to the State of Washington and may not be representative of other locales.   | Low        |
| • Characterization of variability      | Variability in soil adherence is affected by many factors including soil properties, activity and individual behavior patterns.                           | Low        |
| • Lack of bias in study design         | The studies attempted to measure soil adherence in selected activities and conditions to identify important activities and groups.                        | High       |
| • Measurement error                    | The experimental error is low and well controlled, but application of results to other similar activities may be subject to variation.                    | Low/High   |
| <b>Other Elements</b>                  |   |            |
| • Number of studies                    | The experiments were controlled as they were conducted by a few laboratories; activity patterns were studied by only one laboratory.                      | Medium     |
| • Agreement among researchers          | Results from key study were consistent with earlier estimates from relevant studies and assumptions, but are limited to hand data.                        | Medium     |
| <b>Overall Rating</b>                  | Data are limited, therefore it is difficult to extrapolate from experiments and field observations to general conditions .                                | <b>Low</b> |

1  
2  
3

**APPENDIX 8A**  
**FORMULAE FOR TOTAL BODY SURFACE AREA**

## APPENDIX 8A FORMULAE FOR TOTAL BODY SURFACE AREA

Most formulae for estimating surface area (SA), relate height to weight to surface area. The following formula was proposed by Gehan and George (1970):

$$SA = KW^{2/3} \quad (8A-1)$$

where:

SA = surface area in square meters;  
W = weight in kg; and  
K = constant.

While the above equation has been criticized because human bodies have different specific gravities and because the surface area per unit volume differs for individuals with different body builds, it gives a reasonably good estimate of surface area.

A formula published in 1916 that still finds wide acceptance and use is that of DuBois and DuBois. Their model can be written:

$$SA = a_0 H^{a_1} W^{a_2} \quad (8A-2)$$

where:

SA = surface area in square meters;  
H = height in centimeters; and  
W = weight in kg.

The values of  $a_0$  (0.007182),  $a_1$  (0.725), and  $a_2$  (0.425) were estimated from a sample of only nine individuals for whom surface area was directly measured. Boyd (1935) stated that the DuBois formula was considered a reasonably adequate substitute for measuring surface area. Nomograms for determining surface area from height and mass presented in Volume I of the Geigy Scientific Tables (1981) are based on the DuBois and DuBois formula. In addition, a computerized literature search conducted for this report identified several articles written in the last 10 years in which the DuBois and DuBois formula was used to estimate body surface area.

Boyd (1935) developed new constants for the DuBois and DuBois model based on 231 direct measurements of body surface area found in the literature. These data were limited to measurements of surface area by coating methods (122 cases), surface integration (93 cases), and triangulation (16 cases). The subjects were Caucasians of normal body build for whom data on weight, height, and age (except for exact age of adults) were complete. Resulting values for the constants in the DuBois and DuBois model were  $a_0 = 0.01787$ ,  $a_1 = 0.500$ , and  $a_2 = 0.4838$ . Boyd also developed a formula based exclusively on weight, which was inferior to the DuBois and DuBois formula based on height and weight.

Gehan and George (1970) proposed another set of constants for the DuBois and DuBois model. The constants were based on a total of 401 direct measurements of surface area, height,

1 and weight of all postnatal subjects listed in Boyd (1935). The methods used to measure these  
2 subjects were coating (163 cases), surface integration (222 cases), and triangulation (16 cases).

3 Gehan and George (1970) used a least-squares method to identify the values of the  
4 constants. The values of the constants chosen are those that minimize the sum of the squared  
5 percentage errors of the predicted values of surface area. This approach was used because the  
6 importance of an error of 0.1 square meter depends on the surface area of the individual. Gehan  
7 and George (1970) used the 401 observations summarized in Boyd (1935) in the least-squares  
8 method. The following estimates of the constants were obtained:  $a_0 = 0.02350$ ,  $a_1 = 0.42246$ ,  
9 and  $a_2 = 0.51456$ . Hence, their equation for predicting SA is:

$$SA = 0.02350 H^{0.42246} W^{0.51456} \quad (8A-3)$$

10  
11 or in logarithmic form:

$$\ln SA = -3.75080 + 0.42246 \ln H + 0.51456 \ln W \quad (8A-4)$$

12  
13 where:

14 SA = surface area in square meters;

15 H = height in centimeters; and

16 W = weight in kg.

17  
18  
19 This prediction explains more than 99 percent of the variations in surface area among the  
20 401 individuals measured (Gehan and George, 1970).

21 The equation proposed by Gehan and George (1970) was determined by the U.S. EPA  
22 (1985) as the best choice for estimating total body surface area. However, the paper by Gehan  
23 and George gave insufficient information to estimate the standard error about the regression.  
24 Therefore, the 401 direct measurements of children and adults (i.e., Boyd, 1935) were reanalyzed  
25 in U.S. EPA (1985) using the formula of Dubois and Dubois (1916) and the Statistical  
26 Processing System (SPS) software package to obtain the standard error.

27 The Dubois and Dubois (1916) formula uses weight and height as independent variables to  
28 predict total body surface area (SA), and can be written as:

$$SA_i = a_0 H_i^{a_1} W_i^{a_2} e_i \quad (8A-5)$$

29  
30 or in logarithmic form:

$$\ln(SA)_i = \ln a_0 + a_1 \ln H_i + a_2 \ln W_i + \ln e_i \quad (8A-6)$$

where:

- Sai = surface area of the i-th individual (m<sup>2</sup>);
- Hi = height of the i-th individual (cm);
- Wi = weight of the i-th individual (kg);
- a<sub>0</sub>, a<sub>1</sub>, and a<sub>2</sub> = parameters to be estimated; and
- e<sub>i</sub> = a random error term with mean zero and constant variance.

Using the least squares procedure for the 401 observations, the following parameter estimates and their standard errors were obtained:

$$a_0 = -3.73(0.18), a_1 = 0.417(0.054), a_2 = 0.517(0.022)$$

The model is then:

$$SA = 0.0239H^{0.417}W^{0.517} \quad (8A-7)$$

or in logarithmic form:

$$\ln SA = -3.73 + 0.417 \ln H + 0.517 \ln W \quad (8A-8)$$

with a standard error about the regression of 0.00374. This model explains more than 99 percent of the total variation in surface area among the observations, and is identical to two significant figures with the model developed by Gehan and George (1970).

When natural logarithms of the measured surface areas are plotted against natural logarithms of the surface predicted by the equation, the observed surface areas are symmetrically distributed around a line of perfect fit, with only a few large percentage deviations. Only five subjects differed from the measured value by 25 percent or more. Because each of the five subjects weighed less than 13 pounds, the amount of difference was small. Eighteen estimates differed from measurements by 15 to 24 percent. Of these, 12 weighed less than 15 pounds each, 1 was overweight (5 feet 7 inches, 172 pounds), 1 was very thin (4 feet 11 inches, 78 pounds), and 4 were of average build. Since the same observer measured surface area for these 4 subjects, the possibility of some bias in measured values cannot be discounted (Gehan and George 1970).

Gehan and George (1970) also considered separate constants for different age groups: less than 5 years old, 5 years old to less than 20 years old, and greater than 20 years old. The different values for the constants are presented below:

Table 8A-1. Estimated Parameter Values for Different Age Intervals

| Age group           | Number of persons | $a_0$   | $a_1$   | $a_2$   |
|---------------------|-------------------|---------|---------|---------|
| All ages            | 401               | 0.02350 | 0.42246 | 0.51456 |
| <5 years old        | 229               | 0.02667 | 0.38217 | 0.53937 |
| ≥ 5 - <20 years old | 42                | 0.03050 | 0.35129 | 0.54375 |
| ≥ 20 years old      | 30                | 0.01545 | 0.54468 | 0.46336 |

The surface areas estimated using the parameter values for all ages were compared to surface areas estimated by the values for each age group for subjects at the 3rd, 50th, and 97th percentiles of weight and height. Nearly all differences in surface area estimates were less than 0.01 square meter, and the largest difference was 0.03 m<sup>2</sup> for an 18-year-old at the 97th percentile. The authors concluded that there is no advantage in using separate values of  $a_0$ ,  $a_1$ , and  $a_2$  by age interval.

Haycock et al. (1978) without knowledge of the work by Gehan and George (1970), developed values for the parameters  $a_0$ ,  $a_1$ , and  $a_2$  for the DuBois and DuBois model. Their interest in making the DuBois and DuBois model more accurate resulted from their work in pediatrics and the fact that DuBois and DuBois (1916) included only one child in their study group, a severely undernourished girl who weighed only 13.8 pounds at age 21 months. Haycock et al. (1978) used their own geometric method for estimating surface area from 34 body measurements for 81 subjects. Their study included newborn infants (10 cases), infants (12 cases), children (40 cases), and adult members of the medical and secretarial staffs of 2 hospitals (19 cases). The subjects all had grossly normal body structure, but the sample included subjects of widely varying physique ranging from thin to obese. Black, Hispanic, and white children were included in their sample. The values of the model parameters were solved for the relationship between surface area and height and weight by multiple regression analysis. The least squares best fit for this equation yielded the following values for the three coefficients:  $a_0 = 0.024265$ ,  $a_1 = 0.3964$ , and  $a_2 = 0.5378$ . The result was the following equation for estimating surface area:

$$SA = 0.024265H^{0.3964}W^{0.5378} \quad (8A-9)$$

expressed logarithmically as:

$$\ln SA = \ln 0.024265 + 0.3964 \ln H + 0.5378 \ln W \quad (8A-10)$$

The coefficients for this equation agree remarkably with those obtained by Gehan and George (1970) for 401 measurements.

George et al. (1979) agree that a model more complex than the model of DuBois and DuBois for estimating surface area is unnecessary. Based on samples of direct measurements by Boyd (1935) and Gehan and George (1970), and samples of geometric estimates by Haycock et al. (1978), these authors have obtained parameters for the DuBois and DuBois model that are different than those originally postulated in 1916. The DuBois and DuBois model can be written logarithmically as:

$$\ln SA = \ln a_0 = a_1 \ln H + a_2 \ln W \quad (8A-11)$$

The values for  $a_0$ ,  $a_1$ , and  $a_2$  obtained by the various authors discussed in this section are presented to follow:

Table 8A-2. Summary of Surface Area Parameter Values for the Dubois and Dubois Model

| Author<br>(year)            | Number<br>of persons | $a_0$    | $a_1$   | $a_2$   |
|-----------------------------|----------------------|----------|---------|---------|
| DuBois and DuBois<br>(1916) | 9                    | 0.007184 | 0.725   | 0.425   |
| Boyd (1935)                 | 231                  | 0.01787  | 0.500   | 0.4838  |
| Gehan and George<br>(1970)  | 401                  | 0.02350  | 0.42246 | 0.51456 |
| Haycock et al. (1978)       | 81                   | 0.024265 | 0.3964  | 0.5378  |

The agreement between the model parameters estimated by Gehan and George (1970) and Haycock et al. (1978) is remarkable in view of the fact that Haycock et al. (1978) were unaware of the previous work. Haycock et al. (1978) used an entirely different set of subjects, and used geometric estimates of surface area rather than direct measurements. It has been determined that the Gehan and George model is the formula of choice for estimating total surface area of the body since it is based on the largest number of direct measurements.

### ***Nomograms***

Sendroy and Cecchini (1954) proposed a graphical method whereby surface area could be read from a diagram relating height and weight to surface area. However, they do not give an explicit model for calculating surface area. The graph was developed empirically based on 252 cases, 127 of which were from the 401 direct measurements reported by Boyd (1935). In the other 125 cases the surface area was estimated using the linear method of DuBois and DuBois (1916). Because the Sendroy and Cecchini method is graphical, it is inherently less precise and less accurate than the formulae of other authors discussed above.